A Subject-Specific Human Body Model Validation Workflow for Post-Mortem Human Subject Test Reconstruction.

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I. INTRODUCTION

Virtual testing with human body models (HBMs) is increasingly important in vehicle crash safety, as HBMs provide greater anatomical fidelity and can represent a wider range of subject size, shape, and posture than anthropomorphic test devices [1]. This capability is particularly valuable as safety assessments expand beyond standard reference occupants and nominal seating conditions [2]. However, current finite-element HBMs are commonly validated using scaled post-mortem human subject (PMHS) response corridors that do not fully capture important variation in anatomy and posture. This limitation is especially relevant in whole-body frontal tests, where body geometry, alignment, and restraint interaction influence loading and kinematic response [3–4]. Prior studies have shown that closer matching of anthropometry, posture, and body shape can improve correlation with PMHS data [5–6]. Subject-specific model validation therefore offers a realistic approach, in which a baseline HBM is morphed to represent an individual PMHS, the test setup is reconstructed, and predicted responses are compared with the corresponding experimental data. The objective of this study is to present a practical workflow for subject-specific PMHS setup reconstruction in frontal impact simulation, with emphasis on geometry matching, posture definition, belt fitting, and pre-impact settling.

II. METHODS

A simplified Global Human Body Models Consortium (GHBMC) finite-element HBM (M50-OS) was used as the baseline model. A subject-specific HBM was developed for the PMHS by morphing this baseline model to target subject geometry using UMTRI's mesh-morphing framework [6–7]. The target geometry was initially defined using statistically predicted skeletal geometry and external body shape based on subject covariates, including age, sex, stature, and BMI [8–13]. To further increase subject specificity, ribcage and pelvis geometries were extracted from PMHS computed tomography (CT) data and PC-fitted to the corresponding anatomical structures using the statistical model to identify the principal components (PC) that best matched the CT-derived subject anatomy (Fig. 1). These PC-fitted ribcage and pelvis structures were then integrated into the subject-specific HBM, thereby improving representation of internal skeletal geometry beyond the initial statistically predicted model.

After geometry matching, the morphed model was repositioned to reproduce the pre-impact sled-test configuration using measured kinematic and accelerometer-based target data. The HBM was first translated to the measured mid-hip location, and the pelvis was rotated about this point to match measured pelvis angle. The torso (T1, T8, and T12) and head centre of gravity were then aligned to corresponding target measurements, and lower extremities were positioned using femoral mid-shaft, tibial mid-shaft, and ankle targets. Once the skeletal configuration was established, surrounding soft tissues were re-morphed to conform to the updated posture.

A pre-simulation step was then performed to compress soft tissues and establish a realistic pre-impact subject-seat interaction state by removing initial penetrations and allowing the model to settle into the seat. Belt fitting was subsequently performed using measured belt target data, with the belt routed as close as possible to the target locations on the body surface while avoiding initial penetration; buckle, retractor, and knee bolster locations were also aligned to the corresponding tracker data. These steps were intended to reproduce the initial restraint and contact conditions as closely as possible before impact. The resulting subject-specific HBM was then ready for frontal impact simulation and comparison with the corresponding PMHS response (Fig. 2A).

III. INITIAL FINDINGS

The proposed workflow (Fig. 1 and 2) generated subject-specific HBMs that were progressively refined from initial geometry matching to simulation-ready PMHS test reconstruction. Initial results indicate that the workflow was able to reproduce key components of the sled-test setup in a structured and repeatable manner, including subject geometry, seated posture, belt routing, and pre-impact subject-seat interaction. The comparison in Fig. 2B further showed that the subject-specific HBM achieved closer agreement with the PMHS setup than the

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baseline HBM, particularly in body geometry and anatomical landmark locations.

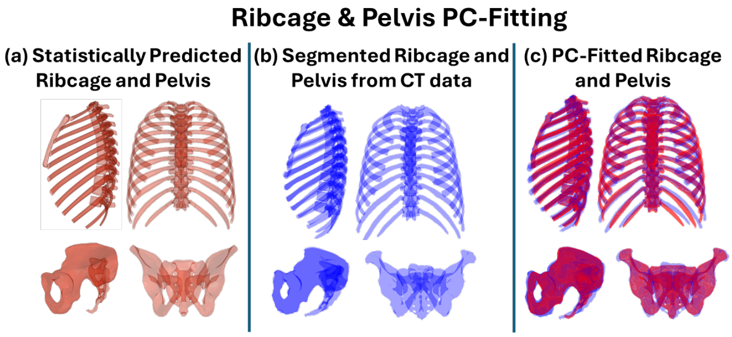

Fig. 1. Subject-specific ribcage and pelvis matching using principal component (PC) fitting.

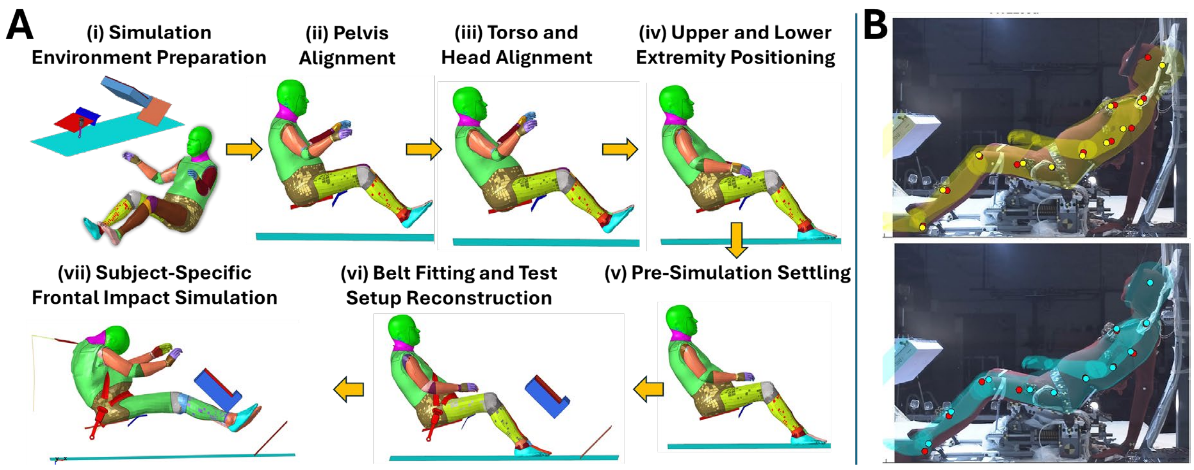

Fig. 2. (A) Workflow for subject-specific post-mortem human subject (PMHS) test reconstruction. (B) Comparison of the PMHS setup overlaid with the baseline HBM (top) and the subject-specific HBM (bottom), showing improved agreement in overall body geometry and anatomical landmark.

IV. DISCUSSION

The present workflow moves subject-specific model validation beyond generic corridor comparison toward explicit reconstruction of the tested subject's geometry, posture, belt fit, and seat interaction state. This is important because agreement with PMHS response depends not only on model biofidelity, but also on accurate reconstruction of the initial test setup. Prior studies have shown that closely matching anthropometry and posture improves correlation with PMHS outcomes [5–6], and further improvement is expected from incorporating subject-specific skeletal geometry and external body shape, together with positioning, settling, and belt fitting, to better reconstruct the initial PMHS test condition. In frontal impact tests with seat belt restraint, skeletal geometry, bone orientation, body shape, posture, and seat settling all influence belt interaction and subject kinematics. As a result, inaccuracies in alignment, belt routing, or seat interaction may propagate into differences in belt engagement, torso motion, and injury-related responses, and may otherwise be misinterpreted for limitations in model biofidelity rather than setup fidelity. Future work will apply this workflow to compare model-predicted kinematics, restraint interaction, and injury-related measures with corresponding PMHS data.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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